REPORT AD-A274 593

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE 29 October 1993	3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE Test Operations Procedure (TOP) 1-2-618 Initial Nuclear Radiation Hardness Validation Test	5. FUNDING NUMBERS
6. AUTHOR(S)	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Commander U.S. Army White Sands Missile Range ATTN: STEWS-NE-A WSMR, NM 88002	8. PERFORMING ORGANIZATION REPORT NUMBER Test Operations Procedure (TOP) 1-2-618
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander U.S. Army Test and Evaluation Command ATTN: AMSTE-CT-T Aberdeen Proving Ground, MD 21005-5055	10. SPONSORING/MONITORING AGENCY REPORT NUMBER Same as item 8

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release:
Distribution unlimited

94-01358

13. ABSTRACT (*Maximum 200 words*)

This TOP describes the techniques, procedures, and general outline required to assess the effects of the initial nuclear radiation environment on Army material. All facets of initial nuclear radiation test preparation, test execution and test documentation are covered in this TOP.

14. SUBJECT TERMS Gamma dose rate Total gamma dose Neutron fluence	15. NUMBER OF PAGES 23
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2 89)
Prescribed by ANSI Std Z39-18
298-102

94 1 11 129

US ARMY TEST AND EVALUATION COMMAND
TEST OPERATION PROCEDURES

Test Operations Procedure (TOP) 1-2-618 — 29 October 1993
AD No.

INITIAL NUCLEAR RADIATION HARDNESS VALIDATION TEST

1. SCOPE.

This Test Operation Procedure (TOP) is an outline of the test and analysis procedures required to determine the effects of the Initial Nuclear Radiation (INR) environments on Army materiel. The purpose of this test and analysis procedure is to ascertain the degree to which the Mission Need Statement (MNS) and/or Operational Requirements Document (ORD) and the Army Nuclear Hardening Criteria (NHC) are met. Army materiel can consist of a variety of configurations, such as complete end items. subsystems, Line Replaceable Units (LRUs), or electronic microcircuits. All materiel must be tested and evaluated to its NHC with respect to all mission essential functions. Realistic and practical test configurations and scenarios must be contemplated in order to achieve an accurate and complete Nuclear Survivability Assessment (NSA). All NSAs must include a three phase approach in order to meet the requirements of Department of Defense Instruction (DODI) 5000.2[1*], AR70-60[2] and its NHC[3]. The three phases are the electronic microcircuit test phase, the system analysis phase, and the system level test phase. The combination of these three phases will result in an overall micro-to-macro system INR survivability determination. This TOP adheres to an integrated set of test principles and procedures which will result in a timely, reliable, and consistent analysis of the system level test phase. The scope of this TOP does not include an in depth education in the theory of creation or measurement of the nuclear environments.

2. GENERAL TEST CONSIDERATIONS.

2.1 Test Preparation.

*Superscript numbers/letters correspond to those in Appendix C, References.
Approved for public release; Distribution Unlimited.

Test preparation should be performed in accordance with TOP 1-2-612[4] Section 3.1. As indicated above, this TOP describes the methods of performing a system level INR test and analysis. It cannot be over emphasized that a complete NSA program also requires electronic microcircuit test and analysis and a system circuit analysis phase. All three phases are critical in providing the entire micro-to-macro model analysis of a system.

2.2 Facilities and Instrumentation.

Approved DOD INR facilities available for testing are listed in Defense Nuclear Agency (DNA) publication, DASIAC SR-90-252, "Guide to Nuclear Weapons Effects Simulator Facilities and Techniques", (1990 Edition). Facility instrumentation shall include, as a minimum, that which is required to record and characterize the simulated INR environment. The INR environment requires characterization by dosimetry methods which are traceable to the National Institute of Standards and Technology (NIST formally the National Bureau of Standards NBS) with a minimum acceptable predicted accuracy of ±10%. Before any testing begins, the ability to meet these requirements must be established through interface with the facility specialists. System specific instrumentation should be coordinated with the facility/test agency.

2.3 Test Chronology.

All effects produced by a nuclear weapon are dependent upon weapon yield, type of burst, height of burst (HOB), and distance. Figure 1 presents the time history of environments produced by a 27 kilo-TON weapon detonated at a HOB of 180m at a distance of 1km (Please note that Figure 1 is a chronological representation of the environments only and is not intended as a reference; should further references be required refer to APPENDIX C). As is indicated in the figure (y-axis values are normalized per environment and do not represent any relationship in magnitudes), the first environment to arrive at the location of interest will be the gamma environments (this includes the gamma dose rate and prompt gamma total dose). This is followed by a continuing gamma total dose environment (at a much lower deposition rate) and then a short time later by the neutron fluence environment. This environment delivery scheme provides a simple test chronology. The gamma dose rate is always tested as the first environment of the NSA followed by the gamma total dose and finally the neutron environments. As can be seen in the figure, approximately 50% of the gamma total dose is provided before and 50% of the gamma total dose is provided after the arrival of the neutrons. The physics of damage in common electronic microcircuits to the low dose rate gamma total dose and neutron environments is such that the environments can be performed in either order. However, the physics of damage in common electronic microcircuits when exposed to the gamma dose rate environment is such that this test can never follow the neutron environment. This is due to the fact that most microcircuit damage is incurred as a result of gamma dose rate induced latchup. This latchup is characterized by the microcircuit entering an non-functional state and consuming excessive power supply current. These excessive currents can damage the microcircuit through thermal breakdown of the semiconductor material or device metalization. The latchup path is part of the microcircuit physical layout and is the unintentional creation of parasitic secondary devices which resemble Silicon Controlled Rectifiers (SCRs). The functioning of these secondary SCRs can be greatly influenced by the neutron environment which will degrade the overall gain of the parasitic SCR (high levels of neutron fluence exposure have been used as a means of hardening certain types of microcircuits by eliminating the gamma dose rate induced latchup mechanism in susceptible microcircuits). Therefore, the neutron fluence environment can never be performed before the gamma dose rate environment.

2.4 Determination of Effects.

The determination of effects of each of the tests outlined in this TOP are based on measures taken after the tests which indicate damage incurred by the item as a result of a particular test. In order to fully characterize any potential damage, the post-test measures must be reviewed in light of the baseline pre-test measures. These measures may be unique to the type of item being tested and several measures may by utilized. The measures should reflect both the functionality and performance of the item whenever possible. Usually system self-checks are used because they are quickest and the most straight forward, however, priority should be given to identification of a performance-related measure which could be tested after each irradiation relative to the baseline performance.

3. GENERAL RADIATION EFFECTS.

As a prerequisite a familiarity with TOP 1-2-612[4] is recommended. Each INR environment will be addressed separately below:

3.1 Gamma Dose Rate.

3.1.1 Environment Induced Effects.

The primary effect of the gamma dose rate environment is ionization of the material which it is imposed upon. In the case of electronics, this material is some form of semiconductor material. The ionization is evidenced in the generation of gamma photon induced transient currents (photocurrents). These photocurrents produce secondary effects which include 1) error generation in logic and analog circuits, 2) secondary photocurrents, 3) photocurrent induced burnout, 4) latchup, and 5) electronic microcircuit destruction. As can be seen from this variety of effects the gamma dose rate induced response can be as small as an unnoticed error, or as catastrophic as a run away or inoperable system.

3.1.2 General Protection Schemes.

As indicated above, the primary response to the gamma dose rate environment is the production of photocurrents. In silicon, the hole/electron

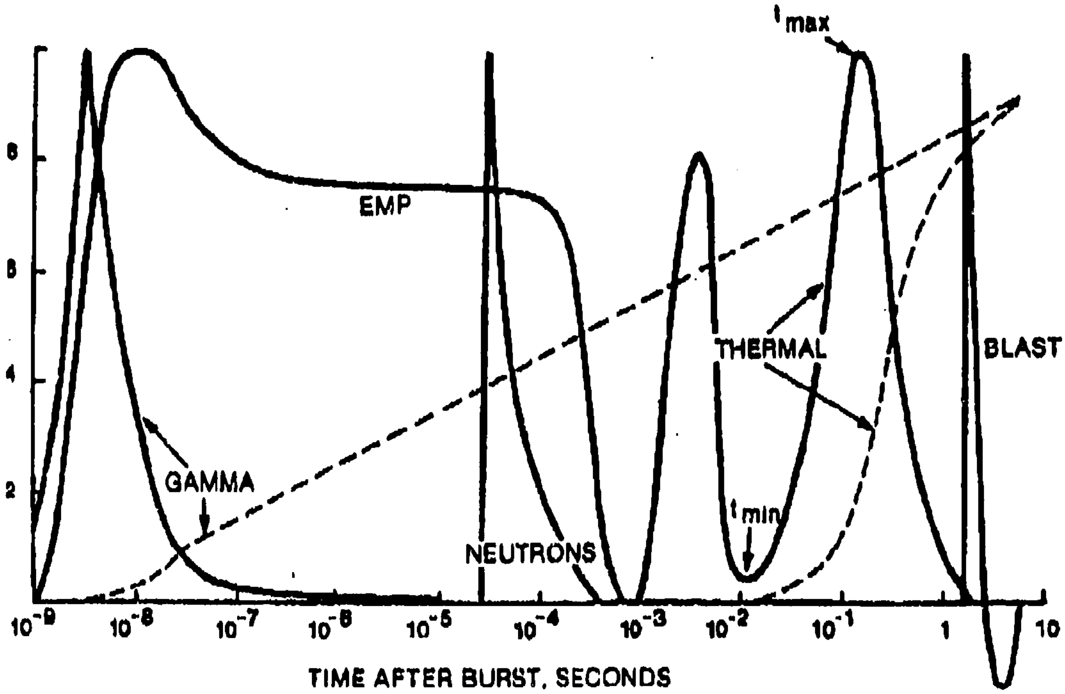

FIGURE #1: Example Time History From 27 kT Nuclear Weapon.

pair produced by 1 RAD(Si) is approximately $4.2X10^{13}$ pairs/cm^3. It is apparent from this pair production rate that the gamma dose rate environment is capable of producing large photocurrents particularly when tens or hundreds of RAD(Si) are involved. The photocurrents generated are limited by the size of the microcircuit active area, the magnitude and energy of the gamma dose rate environment, and the ability of the electronic circuit design to provide paths for these currents. Intuitively, the solutions for the reduction in photo-currents are the reduction in: the microcircuits active area, the gamma dose rate environment, and the circuits capability to handle current. The reduction in the devices active area is accomplished in todays' technology by the use of specially made integrated circuits which use insulator materials as substrates, such as Silicon-On-Sapphire (SOS) or Silicon-on-Insulator (SOI). The reduction in the gamma dose rate environment can be accomplished by the addition of high density material such as lead. The reduction in gamma dose rate environment by shielding in general, is not effective given the system weight and performance degradations. The reduction in circuit current carrying capability is accomplished in three methods: resistive current limiting, inductive current limiting, and power supply crowbaring (gamma dose rate induced circumvention). Each of these three options provide differing circuit aspects which must be considered before the protection technique is selected. In general, the primary method used in systems which do not have an operate through requirement is the gamma dose rate induced circumvention.

3.2 Gamma Total Dose.

The gamma total dose environment includes the effects of both the gamma and X-ray spectrums, with the gamma photons being produced when an excited electron falls to its normal valence shell and emits a photon of energy. This photon is similar to electromagnetic waves which are produced at atomic dimension frequencies. The X-rays are produced as an electron passes near an atom and is changed in direction. This change in direction causes the electron to radiate energy. The radiated energy is called Bremsstrahlung or braking radiation and consists of high energy X-ray photons. For ground based or near surface systems, X-rays are not of direct concern because they are absorbed within a few meters of the detonation.

3.2.1 Environment Induced Effects.

The gamma total dose environment is significant in electronic microcircuits which contain highly resistive isolation techniques such as the Metal Oxide Semiconductor (MOS) devices. The gamma total dose environment produced hole-electron pairs which can have enough energy to be separated by the highly resistive isolation and not allowed to recombine (trapped), resulting in a net microcircuit charge. This residual charge results in a shift in the activation and deactivation threshold levels for the microcircuit. If the shift is significant, the microcircuit will no longer respond as required. This residual charge can also result in the change in logic of a memory storage device, resulting in false instructions being generated.

3.2.2 General Protection Schemes.

There are no general overall hardening procedures to follow (as there were for the gamma dose rate environment) which will reduce the effects of the gamma total dose environment. It has been seen in many microcircuits that the exposure of the electronics while in an unpowered state can considerably improve the total dose survivability level. This implies that very fast responding gamma dose rate induce circumvention is one possible method for improving microcircuit gamma total dose survivability. However, the prime method of improving gamma total dose capabilities is through the use of technologies which are less susceptible. For device comparison, see TABLE #1 which was extracted from TOP 1-2-612[4] TABLE #E-3, subject "INR testing

Requirements for Generic Part Families". The avoidance of NMOS microcircuits is highly recommended since their response has proven to be the worst of all technologies.

TABLE# 1. INR Testing Requirements for Generic Part Families.

Generic Damage Levels:

Gamma Dose Rate: Upset < 1E9 Rad(Si)/sec
Damage < 1E9 Rad(Si)/sec
Based Upon 20 nsec Pulsewidth

Total Gamma Dose: < 1500 Rad(Si)

Neutron Fluence : < 1E12 n/cm^2

Generic Part Family	**Gamma Dose Rate Testing**	**Gamma Total Dose Testing**	**Neutron Fluence Testing**	**Comments**
1. Diodes	No	No	No	
2. PIN Diodes	Yes	No	No	
3. Temperature Compensated Diodes	No	No	Yes	
4. Zener Diodes	No	No	No	
5. High F_T (> 50 MHz) Transistors	No	No	No	
6. Low F_T (< 50 MHz) Transistors	No	No	Yes	
7. Power Transistors	No	No	Yes	
8. Crystals	No	Yes	Yes	
9. Crystals Oscillators	** Yes	Yes	Yes	** Technology Dependent
10. Operational Amplifiers	No	No	Yes	
11. Comparators	Yes	No	Yes	
12. CMOS Analog Switches	Yes	** Yes	Yes	** Certain Manufacturers
13. Fixed Regulators	No	No	Yes	
14. DC to DC Converters	** Yes	** Yes	** Yes	** Technology Dependent

TABLE #1: INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Total Gamma Dose Testing	Neutron Fluence Testing	Comments
15. ADC	** Yes	** Yes	** Yes	** Technology Dependent
16. DAC	** Yes	** Yes	** Yes	** Technology Dependent
17. JFETs	Yes	No	Yes	
18. MOSFETs	Yes	Yes	Yes	
19. Discrete Timers	No	No	No	
20. Linear Timers	No	No	Yes	
21. SCRs	Yes	No	Yes	
22. Unijunction Transistors	No	No	Yes	
23. Discrete Opto-Electronics	No	No	Yes	
24. Opto-Couplers	No	No	Yes	
25. EE PAL	** Yes	** Yes	No	** Technology Dependent
26. TTL PAL	No	No	No	
27. UV PAL	No	Yes	No	
28. EE PROM	** Yes	** Yes	No	** Technology Dependent
29. UV PROM	** Yes	No	No	** Technology Dependent

TABLE #1. INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Total Gamma Dose Testing	Neutron Fluence Testing	Comments
30. TTL PROM	No	No	No	No
31. NMOS PROM	No	Yes	Yes	
32. Static	RAMs	Yes	Yes	No
33. IDT RAMs	Yes	Yes	No	

3.3 Neutron Fluence.

3.3.1 Environment Induced Effects.

The primary effect of the neutron fluence environment are as a result of crystal lattice damage of the semiconductor material which it is imposed upon. Neutrons can also produce ionization as a secondary effect to the crystal lattice displacement and transient responses. These responses are however, short lived and annealing occurs within minutes. The lattice displacement is evidenced in the reduction of microcircuit parameters. These microcircuit parameters are primary influenced by the reduction in minority carrier life time which directly influences the gain of bipolar devices. This reduction in gain effects other circuit parameters such as output current, input current, and operation.

3.3.2 General Protection Schemes.

There are no general overall hardening procedures to follow (as there were for the gamma dose rate environment) which will reduce the effects of the neutron fluence environment. Since the neutron induced degradation is primarily the result of crystal lattice damage, there is little or no difference in the degradation effects if the microcircuit is powered or unpowered. The prime method of improving the neutron fluence survivability of microcircuits is through the use of technologies which are less susceptible and devices which have higher operating speeds and less active silicon lattice volume to be disrupted by the neutrons. For device comparison see TABLE 1 above. A device specification book parameter which can be used in the selection of less susceptible bipolar transistors is the Gain Bandwidth Product (GBP). A generic value of GBP to be used as a cutoff for device selection, can be determined by using the Messenger-Spratt transistor degradation equation. The calculation involves determining a maximum generic degradation which will be allowable and then determining the GBP at the required neutron fluence. The Messenger-Spratt equation is presented as Equation 1 with the GBP equation being presented as Equation 2.

$$\frac{1}{\beta}=\frac{1}{\beta_o}+\frac{\Phi_n}{2\pi \times GBP \times K}$$

EQ1. Messenger-Spratt transistor degradation equation

$$GBP=\frac{\Phi_n \eta}{2\pi K(1-\eta)}$$

EQ2. Generic estimate for minimum GBP

where:

K	=	1.35×10^5 sec/cm^2 for N type silicon
K	=	2.1×10^5 sec/cm^2 for P type silicon
n	=	% of original gain required
β_o	=	pre-exposure HFE
β	=	post-exposure HFE
GBP	=	Gain Bandwidth Product
Φ_n	=	Neutron fluence
π	=	Pi = 3.14159

The primary method of accounting for neutron fluence degradations in microcircuits is to design the electronic circuits so that the overall circuit performance is not degraded. As an example, design the circuits to require less gain than the post neutron value.

4 GAMMA DOSE RATE.

4.1 General Gamma Dose Rate Procedures.

In this section, the general procedures for performing a gamma dose rate test will be discussed. The first requirement is an in-depth familiarity with the system and its normal operation. Without this baseline knowledge, an analysis can not be made. The second requirement is the realization that the gamma dose rate environment will be simulated by some form of electron accelerator. These accelerators are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. As such, these simulators are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level, and also insure that the gamma dose rate protection circuitry is activated by the exposures. The system should also be exposed to increased levels of gamma dose rate to account for the nonadiabatic environment, differences in exposure level due to the inverse square law, errors in dosimetry, system variability due to microcircuit processing differences, and to allow for a safety margin. It is recommended that 200% of the test level be used to offset the limitations of using a small sample size (usually one). Verify that using 200% of the test level is acceptable to the independent assessor/evaluator and program manager or materiel developer.

4.2 Detailed Gamma Dose Rate Procedures.

Presented in TOP 1-2-612[4], section 5.4, is a set of data required while performing a gamma dose rate test. Each of these required data elements will be discussed below:

a. Detailed description of the method of producing the gamma dose rate test environment: including; photographs of the test facility setup showing test system location relative to the gamma radiation source.

Method should be either electron beam or Bremsstrahlung and source specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas where computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data in radiation absorbed dose in silicon (RAD(Si)) and absorbed dose in tissue (RAD (tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate the target-to-source (TTS) distances and then refining these TTSs by taking pretest gamma dose rate environment shots. For each of these characterization shots, a series of Calcium Fluoride (Manganese), $CaF_2(Mn)$, Thermoluminescent Dosimeters (TLDs) are placed on the centerline axis of the simulator and exposed. These pretest mapping dosimeter readings are then utilized to calculate each required TTS distance for a given dose rate environment. This calculation process must be performed for each electronic item to be exposed. The basic equation is presented as Equation 3 and should be verified against the pretest mapping data. An area equal to the area of the LRU active electronics must be mapped at each TTS. This is required in order to define the exposure level and gradients associated with the test, for each LRU.

$$\frac{\dot{\gamma}_{req}}{D^2_{traget}} = \frac{\dot{\gamma}_{map}}{D^2_{map}}$$

EQ3. Gamma Dose Rate inverse square equation

where

D_{map} = the distance from the source to the dosimetry point
D_{target} = the distance from the source to the target
$\dot{\gamma}_{map}$ = gamma dose rate at mapping point
$\dot{\gamma}_{req}$ = gamma dose rate required

Rearranging terms, we have Equation 4 which provides the distance required to achieve a given gamma dose rate environment.

$$D_{target} = D_{map}\sqrt{\frac{\dot{\gamma}_{req}}{\dot{\gamma}_{map}}}$$

EQ4. Target distance determination

c. Information required before a test can begin.

These include system familiarity and descriptions, such as sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the gamma dose rate protection devices (if present) are included and evaluated. In addition it is necessary to insure that: (1) Every electronic assemblage will be properly exposed to the gamma dose rate environment while in a powered operational state, (2) The function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each gamma dose rate exposure, and (3) each assemblage will have mounted to each surface dosimetry for recording the incident gamma dose rate environment and dosimetry for recording the total gamma dose received during the test. The dose rate recording dosimetry must be changed after every exposure. This dosimetry at a minimum should be placed on all vertical surfaces of the LRUs under test, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal gamma dose rate environment of an LRU.

d. Dosimetry from the gamma dose rate environment.

The TLDs should be placed as indicated in the section above and their location used to determine the exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. This total gamma dose measurement is converted to dose rate by Equation 5. The pulse shape of the incident gamma dose rate environment is measured using reverse biased diodes. These reverse biased diodes generate photocurrents which are directly proportional to the incident radiation environment (see section 3.1). By utilizing very fast recovery diodes such as PIN diodes, the photocurrent response tracks the incident radiation very accurately. The gamma dose rate induced current waveforms are then converted to voltage waveforms by a series resistance and this voltage is digitized and stored using digital storage oscilloscopes. From these recorded data, the pulsewidth of the incident environment may be determined.

$$\dot{\gamma}(CaF_2(Mn)) = \frac{\gamma(CaF_2(Mn))}{P_{width}}$$

EQ. 5 Gamma Dose Rate conversion

where:

$\gamma(CaF_2(Mn))$ = gamma dose in $CaF_2(Mn)$
P_{width} = full width at half maximum
$\dot{\gamma}(CaF_2(Mn))$ = gamma dose rate in $CaF_2(Mn)$

The $\gamma(CaF_2(Mn))$ is then converted to Tissue and Silicon radiation absorbed dose by Equations 6 and 7, respectively.

$$\dot{\gamma}(tissue) = \dot{\gamma}(CaF_2) X 1.108$$

EQ. 6 Conversion to RAD(tissue)

$$\dot{\gamma}(Si) = \dot{\gamma}(CaF_2) X 1.02$$

EQ. 7 Conversion to RAD(Si)

e. System orientation and data.

The system must be oriented such that all of the active electronic LRUs are exposed to the gamma dose rate environment while in a powered operational mode. The TTS distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para. 4.1 above. Any LRU which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the gamma dose rate test based on the physical geometry and spatial location of the LRUs of the system under test. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size analyzed (usually one). The data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each gamma dose rate exposure. Dosimetry from all LRUs which have a line of sight path to the gamma dose rate source should be removed (please note to leave those which are for measuring the test sequence total dose) and analyzed for dose rate achieved. Utilizing this real time exposure data, the TTS distance should be refined using EQ 5 through 7 above until the desired environment has been realized.

4.3 Gamma Dose Rate Analytical Procedures.

Section 4.2 provides the methods utilized to obtain data during a gamma dose rate environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any gamma dose rate effects are noted, then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The gamma dose rate test environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effect on the system analysis.

4.4 Gamma Dose Rate Follow up.

Follow up to the initial gamma dose rate environment should be performed for each susceptible area. One problem which has been noted in the gamma dose rate environment is the masking of concurrent problems by the destruction of one component. As was discussed earlier, the primary means of electronic circuit failure in a gamma dose rate environment is through the activation of a parasitic SCR device. These parasitic SCRs demonstrate all of the common circuit parameters of the discrete device, in that they have a minimum holding current and voltage. The magnitude of these parameters for a given device is based on the quality of the design flaw. It has been seen that the holding current of latched devices can vary between 60 and 150 mAmps; therefore, an effect called current hogging can play a role in the gamma dose rate test. The current hogging effect is a result of these differences in parasitic parameters, i.e. the device which has the lowest holding current and voltage may allow other latched microcircuits to unlatch, and thereby, protect or mask the other microcircuits. Because of this effect, it is always a requirement to retest a system or LRU which has experienced a gamma dose rate induced failure to insure that another failure mechanism was not originally masked (i.e. replacing the old current hogging device may allow a new device to be destroyed).

5. GAMMA TOTAL DOSE.

5.1 General Gamma Total Dose Procedures.

In this section, the general procedures for performing a gamma total dose (hereafter referred to as gamma dose) test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, assessment can not be made. The second requirement is the realization that the gamma dose environment will be simulated by some form of Cobalt 60 source. These sources are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently these simulators are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the gamma dose gradients are kept to a minimum. The system should also be exposed to increased levels to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one). Ideally the system should be tested one LRU at a time, in order to reduce exposure gradients and to keep the exposure time to less than one minute.

5.2 Detailed Gamma Dose Procedures.

Presented in TOP 1-2-612[4] section 5.6 is a set of data required while performing a gamma dose test. Each of these required data will be discussed below:

a. Detailed description of the method of producing the gamma dose test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DNA DASIAC SR-90-252 handbook, and requesting a facilities brochure which should contain a description of the radiation producing method (Co_{60} is the preferred source for low dose rate gamma radiation) and specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas were computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data in radiation absorbed dose in silicon (RAD(Si)) and absorbed dose in tissue (RAD(tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate TTS distances and then refining these TTSs by taking pretest gamma dose environment exposures. For each of these characterization exposures a series of TLDs are placed on the centerline axis of the simulator and exposed. These dosimeter readings are then utilized to calculated each required TTS distance for a given dose rate environment and the exposure time required to achieve a given gamma total dose. This calculation process must be performed for each electronic item to be exposed. The basic dose rate equation is presented as EQ3 and should be verified against the pretest mapping data. EQ4 can be used to select the TTS distance for a given dose rate. The gamma dose rate for the total dose test should be selected between 30 and 300 RAD(Si)/sec and result in an exposure time of approximately one minute. The physical dimensions of the system under test will determine what the highest dose rate used will be. The system test position is selected to minimize the gamma dose gradients, which are calculated using EQ4. Once the TTS distance (which maximizes gamma dose rate and minimizes dose gradient) is determined the time of exposure is calculated using Equation 8.

$$t_{exposure} = \frac{\gamma_{req}}{\dot{\gamma}_{map}}$$

EQ8. Time of Exposure

where

γ_{req} = gamma total dose requirement
$\dot{\gamma}_{map}$ = gamma dose rate at mapping point

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the gamma dose rate protection devices (if present) are included and evaluated. In addition, it is necessary to insure that: (1) every electronic assemblage will be properly exposed to the gamma dose environment while in a powered operational state, (2) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the gamma dose environment, and (3) that each assemblage will have mounted to each surface dosimetry for recording the incident gamma dose environment. If gamma dose rate power down has been employed as a circuit protection method, then the gamma dose test should be designed so that the percentage of gamma dose received after the circumvention time, is received with the system in a powered off nonoperational state. The dosimetry at a minimum should be placed on all vertical surfaces (all surfaces if physically possible) of the LRU undertest, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal gamma dose environment of an LRU.

d. Dosimetry from the gamma dose environment.

The TLDs should be placed as indicated in the section above and their location used to determine the gamma exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. The TLD measurement RAD(CaF_2(Mn)) is converted to Tissue and Silicon radiation absorbed dose by EQ. 6 and 7 with the gamma dose rate term replaced by the gamma dose term.

e. System orientation and data.

The system must be oriented such that all of the active electronic LRUs are exposed to the gamma dose environment while in a powered operational mode. The TTS distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial level, the system should be positioned to receive the

200% levels as indicated in para 4.1 above. Any LRU which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the gamma dose test based on the physical geometry and spatial location of LRUs of the system under test. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size analyzed (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each gamma dose exposure. Dosimetry from all LRUs which have a line of sight path to the gamma dose source should be removed (please note to leave those which are for measuring the test sequence total dose) and analyzed for dose achieved. Utilizing this real time exposure data, the TTS distance should be refined using EQ 5 through 8 above until the desired environment has been realized.

5.3 Gamma Dose Analytical Procedures.

Section 5.2 provides the methods utilized to obtain data during a gamma dose environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the orientation in which they were exposed, and the results of the post-test checkouts. If any gamma dose effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The gamma dose test environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effects on the system analysis.

5.4 Gamma Dose Follow up.

Follow up to the initial gamma dose environment should be performed for each susceptible area. This follow up should include both a system or LRU level retest and an electronic microcircuit analysis.

6. NEUTRON FLUENCE.

6.1 General Neutron Fluence Procedures.

In this section, the general procedures for performing a neutron fluence test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, an assessment can not be made. The second requirement is the realization that the neutron fluence environment will be simulated by some form of nuclear reactor. These reactors are all limited in both size and output and are incapable of producing an adiabatic environment over a large area. These reactors all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently the reactors are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the neutron gradients are kept to a minimum. Since the primary damage mechanism for the neutron fluence environment is crystal lattice damage the system under test does not require power during the radiation exposure. Therefore that system should be disassembled to the smallest practical elements in order to reduce neutron exposure gradients and to eliminate the unnecessary neutron activation of non-essential material. By removing and exposing only the active electronic microcircuits the bulk of material making up a system (i.e. shelters, shielding, and enclosures) are not irradiated. Performing the test with the system disassembled reduces the activated volume and thereby reduces the radiation decay (cool down) time and personnel exposures. The system should also be exposed to increased levels in order to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and to allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one).

6.2 Detailed Neutron Fluence Procedures.

Presented in TOP 1-2-612[4] section 5.5 is a set of data required while performing a neutron fluence test. Each of these required data will be discussed below:

a. Detailed description of the method of producing the neutron fluence test environment including photographs of the test facility setup showing test system location relative to the neutron radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DNA DASIAC SR-90-252 handbook, and requesting a facilities brochure which should contain a description of the radiation producing method and specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas were computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data expressed in 1 MeV equivalent (damage in silicon) neutron/cm^2. Because of the extreme control required in the operation of most reactors the facility will maintain a set of control parameters and dosimetry which can be used to accurately predict experimental exposures. Once a familiarity with the facility has been established there is usually little need for a neutron mapping exposure.

This requirement is obtained by taking several pretest neutron fluence environment exposures. For each of these characterization exposures a series of Sulfur activation dosimetry and TLDs are placed on the centerline axis of the proposed experiment position. These dosimeter readings are then utilized to calculated the required source to target distance for a given neutron environment (for a pulse operation) or the exposure time required to achieve a given neutron dose (for a power operation). The method (pulse or power) of receiving neutron fluence is not of importance as long as the received dose is converted to 1 MeV equivalent damage in silicon. The 1 MeV equivalent conversion is used as a normalization factor between the different types of reactors and operations. Reactors in general are of the water moderated style or the free air mass moderated style, with operations being either pulsed or continuous power. Again the best source found for determining experiment location for a given fluence is the reactor operations crew.

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed. In addition, it is necessary to insure that: (1) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the neutron environment, (2) each exposed assemblage will have mounted to each surface dosimetry for recording the incident neutron environment. This dosimetry at a should be placed on the exposed assemblages at a point on the side which corresponds to the midplane of the active electronic microcircuits (this assumes disassembly to the circuit card assembly level).

d. Dosimetry from the neutron environment.

The sulfur pellets and TLDs should be placed as indicated in the section above and their location used to determine the overall neutron exposure for each specific LRU. The primary method of recording the neutron environment is through the use of sulfur pellets which measure the total neutron energy greater than 3 Mev received. The dosimetry must be changed after every exposure. The sulfur measurement (neutrons/cm^2 greater than 3 MeV) is converted to 1 Mev equivalent damage in silicon by a conversion factor (approximately 6.7 for an experiment at 26 inches for the White Sands Missile Range Fast Burst Reactor). This conversion factor is dependent on the neutron spectrum produced by the reactor and the distance at which the test is performed. Therefore the conversion to 1 MeV equivalent is not generic and must be obtained from the facility dosimetry specialist.

e. System orientation and data.

The system must be oriented such that all of the active electronics are exposed to the neutron fluence environment. This should be accomplished at the Circuit Card Assemblies (CCAs) level if possible, inorder to reduce neutron dose gradients. The TTS distance must be measured before each exposure to insure that the required levels are received. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para. 6.1 above. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to manufacturing processes, and to account for the small sample size analyzed (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each neutron exposure. Dosimetry from all LRUs which have been exposed to the neutron fluence environment should be removed and analyzed for the fluence achieved.

6.3 Neutron Fluence Analytical Procedures.

Section 6.2 provides the methods utilized to obtain data during a neutron fluence environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the CCAs which were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any neutron fluence effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The neutron fluence environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effect on the system analysis.

6.4 Neutron Fluence Follow up.

Follow up to the initial neutron fluence environment should be performed for each susceptible area. This follow up should include both an LRU/CCA level retest and an electronic microcircuit analysis. A total system retest will not be required if the CCA functionality can be verified by an electronic bench test.

Recommended changes of this publication should be forwarded to Commander, U.S. Test and Evaluation Command, ATTN: AMSTE-CT-T, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity, Commander, U.S. Army White Sands Missile Range, ATTN: STEWS-NE-AA, Nuclear Effects Directorate, WSMR NM 88002-5002. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the access number (AD No.) printed on the first page.

APPENDIX A ABBREVIATIONS

ADC	- Analog to Digital Converter
$CaF_2(Mn)$	- Calcium Fluoride (Manganese)
CCA	- Circuit Card Assembly
cm	- centi-meter
CMOS	- Complementary Metal Oxide Semiconductor
cGy	- centi-Gray (equivalent to one RAD)
Co_{60}	- Cobalt 60
DAC	- Digital to Analog Converter
DC	- Direct Current
DNA	- Defense Nuclear Agency
DOD	- Department of Defense
DODI	- Department of Defense Instruction
EE PAL	- Electrically Erasable Programmable Array Logic
F_T	- Gain Bandwidth Product
GBP	- Gain Bandwidth Product
HOB	- Height of Burst
INR	- Initial Nuclear Radiation
JFET	- Junction Field Effect Transistor
km	- Kilo-meter
kT	- Kilo-Ton
LRU	- Line Replaceable Unit
m	- meter
MeV	- Million Electron Volts
MNS	- Materiel Needs Statement
MOS	- Metal Oxide Semiconductor

MOSFET contractor	- Metal Oxide Semiconductor Field Effect
NIST	- National Institute of Standards and Technology Formally National Bureau of Standards
NMOS	- N-type Metal Oxide Semiconductor
NSA	- Nuclear Survivability Assessment
NHC	- Nuclear Hardening Criteria
ORD	- Operational Requirements Document
PAL	- Programmable Array Logic
PROM	- Programmable Read Only Memory
RAD	- Radiation Absorbed Dose
Si	- Silicon
SCR	- Silicon Controlled Rectifier
SOI	- Silicon on Insulator
SOS	- Silicon on Sapphire
TLD	- Thermoluminescent Dosimeter
TOP	- Test Operation Procedures
TTL	- Transistor Transistor Logic
TTS	- Target to Source
UV	- Ultra Violet

APPENDIX B GLOSSARY

Dose	A general term denoting the quantity of radiation or energy absorbed. In general dose is specified based on absorbing material.
Dosimeter	Instrument to detect and measure accumulated radiation exposure. A common dosimeter is a pencil-size ionization chamber with a self reading electrometer, which is used for personnel monitoring.
Gamma	Gamma radiation emitted at the time of fission of a nucleus.
Gamma Ray	Short-wavelength electromagnetic radiation (photon) of nuclear origin.
Ionization	The process by which a neutral atom or molecule acquires a positive or negative charge.
MeV	One million electron volts. An electron volt is the amount of energy acquired by an electron when it falls through a potential of 1 volt.
Neutron	A neutral molecular particle of approximately one atomic mass unit.
Neutron Fluence	Integral of all neutrons entering a specific volume.
Nuclear Radiation	Particulate and electromagnetic radiation emitted from atomic nuclei during various nuclear processes.
X-rays	Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extranuclear part of the atom as X-rays.

APPENDIX C REFERENCES

1. AR 70-60: Nuclear Survivability of Army Materiel, 1 Nov 84.

2. DODI 5000.2: Defense Acquisition Program Procedures, 11 May 90.

3. Army Nuclear Hardening Criterion for system under test

4. Test Operations Procedure 1-2-612, Nuclear Environment Survivability, 1992.

REFERECES FOR INFORMATION ONLY

a. DASIAC SR-90-252, 1990 Edition: Guide to Nuclear Weapons Effects Simulation Facilities and Techniques.

b. G.C. Messenger and M.S. Ash, The Effects of Radiation on Electronic Systems, published by Van Mostrand Reinhold, 1986.

c. S. Glasstone and P.J. Dolan, The Effects of Nuclear Weapons, published by United States Department of Defense and United States Department of Energy, 1977.

d. Illinois Institute Of Technology Research Institute, Nuclear Weapon Effects Class Notes, 1991.

e. White Sands Nuclear Effects Facility Technical Capabilities, Nuclear Effects Directorate, 1992.

US ARMY TEST AND EVALUATION COMMAND
TEST OPERATION PROCEDURES

Test Operations Procedure (TOP) 1-2-618 29 October 1993
AD No.

INITIAL NUCLEAR RADIATION HARDNESS VALIDATION TEST

1. SCOPE.

This Test Operation Procedure (TOP) is an outline of the test and analysis procedures required to determine the effects of the Initial Nuclear Radiation (INR) environments on Army materiel. The purpose of this test and analysis procedure is to ascertain the degree to which the Mission Need Statement (MNS) and/or Operational Requirements Document (ORD) and the Army Nuclear Hardening Criteria (NHC) are met. Army materiel can consist of a variety of configurations, such as complete end items, subsystems, Line Replaceable Units (LRUs), or electronic microcircuits. All materiel must be tested and evaluated to its NHC with respect to all mission essential functions. Realistic and practical test configurations and scenarios must be contemplated in order to achieve an accurate and complete Nuclear Survivability Assessment (NSA). All NSAs must include a three phase approach in order to meet the requirements of Department of Defense Instruction (DODI) 5000.2[1*], AR70-60[2] and its NHC[3]. The three phases are the electronic microcircuit test phase, the system analysis phase, and the system level test phase. The combination of these three phases will result in an overall micro-to-macro system INR survivability determination. This TOP adheres to an integrated set of test principles and procedures which will result in a timely, reliable, and consistent analysis of the system level test phase. The scope of this TOP does not include an in depth education in the theory of creation or measurement of the nuclear environments.

2. GENERAL TEST CONSIDERATIONS.

2.1 Test Preparation.

*Superscript numbers/letters correspond to those in Appendix C, References.
Approved for public release; Distribution Unlimited.

Test preparation should be performed in accordance with TOP 1-2-612[4] Section 3.1. As indicated above, this TOP describes the methods of performing a system level INR test and analysis. It cannot be over emphasized that a complete NSA program also requires electronic microcircuit test and analysis and a system circuit analysis phase. All three phases are critical in providing the entire micro-to-macro model analysis of a system.

2.2 Facilities and Instrumentation.

Approved DOD INR facilities available for testing are listed in Defense Nuclear Agency (DNA) publication, DASIAC SR-90-252, "Guide to Nuclear Weapons Effects Simulator Facilities and Techniques", (1990 Edition). Facility instrumentation shall include, as a minimum, that which is required to record and characterize the simulated INR environment. The INR environment requires characterization by dosimetry methods which are traceable to the National Institute of Standards and Technology (NIST formally the National Bureau of Standards NBS) with a minimum acceptable predicted accuracy of ±10%. Before any testing begins, the ability to meet these requirements must be established through interface with the facility specialists. System specific instrumentation should be coordinated with the facility/test agency.

2.3 Test Chronology.

All effects produced by a nuclear weapon are dependent upon weapon yield, type of burst, height of burst (HOB), and distance. Figure 1 presents the time history of environments produced by a 27 kilo-TON weapon detonated at a HOB of 180m at a distance of 1km (Please note that Figure 1 is a chronological representation of the environments only and is not intended as a reference; should further references be required refer to APPENDIX C). As is indicated in the figure (y-axis values are normalized per environment and do not represent any relationship in magnitudes), the first environment to arrive at the location of interest will be the gamma environments (this includes the gamma dose rate and prompt gamma total dose). This is followed by a continuing gamma total dose environment (at a much lower deposition rate) and then a short time later by the neutron fluence environment. This environment delivery scheme provides a simple test chronology. The gamma dose rate is always tested as the first environment of the NSA followed by the gamma total dose and finally the neutron environments. As can be seen in the figure, approximately 50% of the gamma total dose is provided before and 50% of the gamma total dose is provided after the arrival of the neutrons. The physics of damage in common electronic microcircuits to the low dose rate gamma total dose and neutron environments is such that the environments can be performed in either order. However, the physics of damage in common electronic microcircuits when exposed to the gamma dose rate environment is such that this test can never follow the neutron environment. This is due to the fact that most microcircuit damage is incurred as a result of gamma dose rate induced latchup. This latchup is characterized by the microcircuit entering an non-functional state and consuming excessive power supply current. These excessive currents can damage the microcircuit through thermal breakdown of the semiconductor material or device metalization. The latchup path is part of the microcircuit physical layout and is the unintentional creation of parasitic secondary devices which resemble Silicon Controlled Rectifiers (SCRs). The functioning of these secondary SCRs can be greatly influenced by the neutron environment which will degrade the overall gain of the parasitic SCR (high levels of neutron fluence exposure have been used as a means of hardening certain types of microcircuits by eliminating the gamma dose rate induced latchup mechanism in susceptible microcircuits). Therefore, the neutron fluence environment can never be performed before the gamma dose rate environment.

2.4 Determination of Effects.

The determination of effects of each of the tests outlined in this TOP are based on measures taken after the tests which indicate damage incurred by the item as a result of a particular test. In order to fully characterize any potential damage, the post-test measures must be reviewed in light of the baseline pre-test measures. These measures may be unique to the type of item being tested and several measures may by utilized. The measures should reflect both the functionality and performance of the item whenever possible. Usually system self-checks are used because they are quickest and the most straight forward, however, priority should be given to identification of a performance-related measure which could be tested after each irradiation relative to the baseline performance.

3. GENERAL RADIATION EFFECTS.

As a prerequisite a familiarity with TOP 1-2-612[4] is recommended. Each INR environment will be addressed separately below:

3.1 Gamma Dose Rate.

3.1.1 Environment Induced Effects.

The primary effect of the gamma dose rate environment is ionization of the material which it is imposed upon. In the case of electronics, this material is some form of semiconductor material. The ionization is evidenced in the generation of gamma photon induced transient currents (photocurrents). These photocurrents produce secondary effects which include 1) error generation in logic and analog circuits, 2) secondary photocurrents, 3) photocurrent induced burnout, 4) latchup, and 5) electronic microcircuit destruction. As can be seen from this variety of effects the gamma dose rate induced response can be as small as an unnoticed error, or as catastrophic as a run away or inoperable system.

3.1.2 General Protection Schemes.

As indicated above, the primary response to the gamma dose rate environment is the production of photocurrents. In silicon, the hole/electron

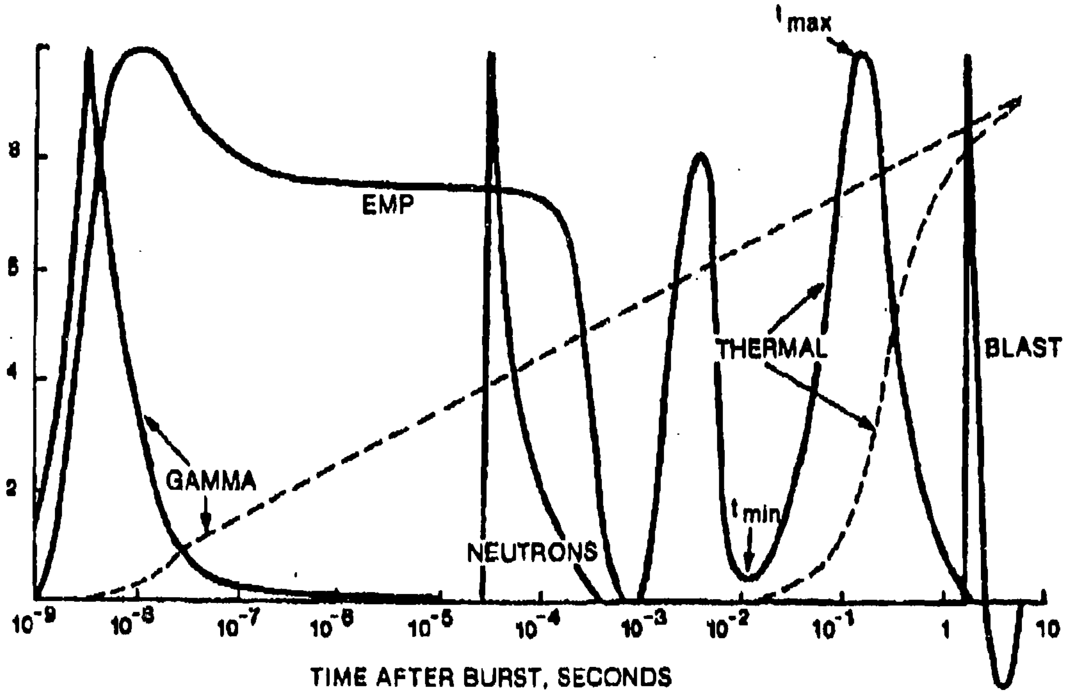

FIGURE #1: Example Time History From 27 kT Nuclear Weapon.

pair produced by 1 RAD(Si) is approximately $4.2X10^{13}$ pairs/cm^3. It is apparent from this pair production rate that the gamma dose rate environment is capable of producing large photocurrents particularly when tens or hundreds of RAD(Si) are involved. The photocurrents generated are limited by the size of the microcircuit active area, the magnitude and energy of the gamma dose rate environment, and the ability of the electronic circuit design to provide paths for these currents. Intuitively, the solutions for the reduction in photo-currents are the reduction in: the microcircuits active area, the gamma dose rate environment, and the circuits capability to handle current. The reduction in the devices active area is accomplished in todays' technology by the use of specially made integrated circuits which use insulator materials as substrates, such as Silicon-On-Sapphire (SOS) or Silicon-on-Insulator (SOI). The reduction in the gamma dose rate environment can be accomplished by the addition of high density material such as lead. The reduction in gamma dose rate environment by shielding in general, is not effective given the system weight and performance degradations. The reduction in circuit current carrying capability is accomplished in three methods: resistive current limiting, inductive current limiting, and power supply crowbaring (gamma dose rate induced circumvention). Each of these three options provide differing circuit aspects which must be considered before the protection technique is selected. In general, the primary method used in systems which do not have an operate through requirement is the gamma dose rate induced circumvention.

3.2 Gamma Total Dose.

The gamma total dose environment includes the effects of both the gamma and X-ray spectrums, with the gamma photons being produced when an excited electron falls to its normal valence shell and emits a photon of energy. This photon is similar to electromagnetic waves which are produced at atomic dimension frequencies. The X-rays are produced as an electron passes near an atom and is changed in direction. This change in direction causes the electron to radiate energy. The radiated energy is called Bremsstrahlung or braking radiation and consists of high energy X-ray photons. For ground based or near surface systems, X-rays are not of direct concern because they are absorbed within a few meters of the detonation.

3.2.1 Environment Induced Effects.

The gamma total dose environment is significant in electronic microcircuits which contain highly resistive isolation techniques such as the Metal Oxide Semiconductor (MOS) devices. The gamma total dose environment produced hole-electron pairs which can have enough energy to be separated by the highly resistive isolation and not allowed to recombine (trapped), resulting in a net microcircuit charge. This residual charge results in a shift in the activation and deactivation threshold levels for the microcircuit. If the shift is significant, the microcircuit will no longer respond as required. This residual charge can also result in the change in logic of a memory storage device, resulting in false instructions being generated.

3.2.2 General Protection Schemes.

There are no general overall hardening procedures to follow (as there were for the gamma dose rate environment) which will reduce the effects of the gamma total dose environment. It has been seen in many microcircuits that the exposure of the electronics while in an unpowered state can considerably improve the total dose survivability level. This implies that very fast responding gamma dose rate induce circumvention is one possible method for improving microcircuit gamma total dose survivability. However, the prime method of improving gamma total dose capabilities is through the use of technologies which are less susceptible. For device comparison, see TABLE #1 which was extracted from TOP 1-2-612[4] TABLE #E-3, subject "INR testing

Requirements for Generic Part Families". The avoidance of NMOS microcircuits is highly recommended since their response has proven to be the worst of all technologies.

TABLE# 1. INR Testing Requirements for Generic Part Families.

Generic Damage Levels:

Gamma Dose Rate: Upset < 1E9 Rad(Si)/sec
Damage < 1E9 Rad(Si)/sec
Based Upon 20 nsec Pulsewidth

Total Gamma Dose: < 1500 Rad(Si)

Neutron Fluence : < 1E12 n/cm^2

Generic Part Family	Gamma Dose Rate Testing	Gamma Total Dose Testing	Neutron Fluence Testing	Comments
1. Diodes	No	No	No	
2. PIN Diodes	Yes	No	No	
3. Temperature Compensated Diodes	No	No	Yes	
4. Zener Diodes	No	No	No	
5. High F_T (> 50 MHz) Transistors	No	No	No	
6. Low F_T (< 50 MHz) Transistors	No	No	Yes	
7. Power Transistors	No	No	Yes	
8. Crystals	No	Yes	Yes	
9. Crystals Oscillators	** Yes	Yes	Yes	** Technology Dependent
10. Operational Amplifiers	No	No	Yes	
11. Comparators	Yes	No	Yes	
12. CMOS Analog Switches	Yes	** Yes	Yes	** Certain Manufacturers
13. Fixed Regulators	No	No	Yes	
14. DC to DC Converters	** Yes	** Yes	** Yes	** Technology Dependent

TABLE #1: INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Total Gamma Dose Testing	Neutron Fluence Testing	Comments
15. ADC	** Yes	** Yes	** Yes	** Technology Dependent
16. DAC	** Yes	** Yes	** Yes	** Technology Dependent
17. JFETs	Yes	No	Yes	
18. MOSFETs	Yes	Yes	Yes	
19. Discrete Timers	No	No	No	
20. Linear Timers	No	No	Yes	
21. SCRs	Yes	No	Yes	
22. Unijunction Transistors	No	No	Yes	
23. Discrete Opto-Electronics	No	No	Yes	
24. Opto-Couplers	No	No	Yes	
25. EE PAL	** Yes	** Yes	No	** Technology Dependent
26. TTL PAL	No	No	No	
27. UV PAL	No	Yes	No	
28. EE PROM	** Yes	** Yes	No	** Technology Dependent
29. UV PROM	** Yes	No	No	** Technology Dependent

TABLE #1. INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Total Gamma Dose Testing	Neutron Fluence Testing	Comments
30. TTL PROM	No	No	No	No
31. NMOS PROM	No	Yes	Yes	
32. Static	RAMs	Yes	Yes	No
33. IDT RAMs	Yes	Yes	No	

3.3 Neutron Fluence.

3.3.1 Environment Induced Effects.

The primary effect of the neutron fluence environment are as a result of crystal lattice damage of the semiconductor material which it is imposed upon. Neutrons can also produce ionization as a secondary effect to the crystal lattice displacement and transient responses. These responses are however, short lived and annealing occurs within minutes. The lattice displacement is evidenced in the reduction of microcircuit parameters. These microcircuit parameters are primary influenced by the reduction in minority carrier life time which directly influences the gain of bipolar devices. This reduction in gain effects other circuit parameters such as output current, input current, and operation.

3.3.2 General Protection Schemes.

There are no general overall hardening procedures to follow (as there were for the gamma dose rate environment) which will reduce the effects of the neutron fluence environment. Since the neutron induced degradation is primarily the result of crystal lattice damage, there is little or no difference in the degradation effects if the microcircuit is powered or unpowered. The prime method of improving the neutron fluence survivability of microcircuits is through the use of technologies which are less susceptible and devices which have higher operating speeds and less active silicon lattice volume to be disrupted by the neutrons. For device comparison see TABLE 1 above. A device specification book parameter which can be used in the selection of less susceptible bipolar transistors is the Gain Bandwidth Product (GBP). A generic value of GBP to be used as a cutoff for device selection, can be determined by using the Messenger-Spratt transistor degradation equation. The calculation involves determining a maximum generic degradation which will be allowable and then determining the GBP at the required neutron fluence. The Messenger-Spratt equation is presented as Equation 1 with the GBP equation being presented as Equation 2.

$$\frac{1}{\beta}=\frac{1}{\beta_o}+\frac{\Phi_n}{2\pi\times GBP\times K}$$

EQ1. Messenger-Spratt transistor degradation equation

$$GBP=\frac{\Phi_n\eta}{2\pi K(1-\eta)}$$

EQ2. Generic estimate for minimum GBP

where:

K	= $1.35X10^5$ sec/cm^2 for N type silicon
K	= $2.1X10^5$ sec/cm^2 for P type silicon
n	= % of original gain required
β_o	= pre-exposure HFE
β	= post-exposure HFE
GBP	= Gain Bandwidth Product
Φ_n	= Neutron fluence
π	= Pi = 3.14159

The primary method of accounting for neutron fluence degradations in microcircuits is to design the electronic circuits so that the overall circuit performance is not degraded. As an example, design the circuits to require less gain than the post neutron value.

4. GAMMA DOSE RATE.

4.1 General Gamma Dose Rate Procedures.

In this section, the general procedures for performing a gamma dose rate test will be discussed. The first requirement is an in-depth familiarity with the system and its normal operation. Without this baseline knowledge, an analysis can not be made. The second requirement is the realization that the gamma dose rate environment will be simulated by some form of electron accelerator. These accelerators are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. As such, these simulators are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level, and also insure that the gamma dose rate protection circuitry is activated by the exposures. The system should also be exposed to increased levels of gamma dose rate to account for the nonadiabatic environment, differences in exposure level due to the inverse square law, errors in dosimetry, system variability due to microcircuit processing differences, and to allow for a safety margin. It is recommended that 200% of the test level be used to offset the limitations of using a small sample size (usually one). Verify that using 200% of the test level is acceptable to the independent assessor/evaluator and program manager or materiel developer.

4.2 Detailed Gamma Dose Rate Procedures.

Presented in TOP 1-2-612[4], section 5.4, is a set of data required while performing a gamma dose rate test. Each of these required data elements will be discussed below:

a. Detailed description of the method of producing the gamma dose rate test environment: including; photographs of the test facility setup showing test system location relative to the gamma radiation source.

Method should be either electron beam or Bremsstrahlung and source specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas where computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data in radiation absorbed dose in silicon (RAD(Si)) and absorbed dose in tissue (RAD (tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate the target-to-source (TTS) distances and then refining these TTSs by taking pretest gamma dose rate environment shots. For each of these characterization shots, a series of Calcium Fluoride (Manganese), $CaF_2(Mn)$, Thermoluminescent Dosimeters (TLDs) are placed on the centerline axis of the simulator and exposed. These pretest mapping dosimeter readings are then utilized to calculate each required TTS distance for a given dose rate environment. This calculation process must be performed for each electronic item to be exposed. The basic equation is presented as Equation 3 and should be verified against the pretest mapping data. An area equal to the area of the LRU active electronics must be mapped at each TTS. This is required in order to define the exposure level and gradients associated with the test, for each LRU.

$$\frac{\dot{\gamma}_{req}}{D^2_{traget}} = \frac{\dot{\gamma}_{map}}{D^2_{map}}$$

EQ3. Gamma Dose Rate inverse square equation

where

D_{map} = the distance from the source to the dosimetry point
D_{target} = the distance from the source to the target
$\dot{\gamma}_{map}$ = gamma dose rate at mapping point
$\dot{\gamma}_{req}$ = gamma dose rate required

Rearranging terms, we have Equation 4 which provides the distance required to achieve a given gamma dose rate environment.

$$D_{target}=D_{map}\sqrt{\frac{\dot{\gamma}_{req}}{\dot{\gamma}_{map}}}$$

EQ4. Target distance determination

c. Information required before a test can begin.

These include system familiarity and descriptions, such as sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the gamma dose rate protection devices (if present) are included and evaluated. In addition it is necessary to insure that: (1) Every electronic assemblage will be properly exposed to the gamma dose rate environment while in a powered operational state, (2) The function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each gamma dose rate exposure, and (3) each assemblage will have mounted to each surface dosimetry for recording the incident gamma dose rate environment and dosimetry for recording the total gamma dose received during the test. The dose rate recording dosimetry must be changed after every exposure. This dosimetry at a minimum should be placed on all vertical surfaces of the LRUs under test, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal gamma dose rate environment of an LRU.

d. Dosimetry from the gamma dose rate environment.

The TLDs should be placed as indicated in the section above and their location used to determine the exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. This total gamma dose measurement is converted to dose rate by Equation 5. The pulse shape of the incident gamma dose rate environment is measured using reverse biased diodes. These reverse biased diodes generate photocurrents which are directly proportional to the incident radiation environment (see section 3.1). By utilizing very fast recovery diodes such as PIN diodes, the photocurrent response tracks the incident radiation very accurately. The gamma dose rate induced current waveforms are then converted to voltage waveforms by a series resistance and this voltage is digitized and stored using digital storage oscilloscopes. From these recorded data, the pulsewidth of the incident environment may be determined.

$$\dot{\gamma}\,(CaF_2\,(Mn)\,) = \frac{\gamma\,(CaF_2\,(Mn)\,)}{P_{width}}$$

EQ. 5 Gamma Dose Rate conversion

where:

$\gamma(CaF_2(Mn))$ = gamma dose in $CaF_2(Mn)$
P_{width} = full width at half maximum
$\dot{\gamma}(CaF_2(Mn))$ = gamma dose rate in $CaF_2(Mn)$

The $\gamma(CaF_2(Mn))$ is then converted to Tissue and Silicon radiation absorbed dose by Equations 6 and 7, respectively.

$$\dot{\gamma}\,(tissue) = \dot{\gamma}\,(CaF_2)\,X1.108$$

EQ. 6 Conversion to RAD(tissue)

$$\dot{\gamma}\,(Si) = \dot{\gamma}\,(CaF_2)\,X1.02$$

EQ. 7 Conversion to RAD(Si)

e. System orientation and data.

The system must be oriented such that all of the active electronic LRUs are exposed to the gamma dose rate environment while in a powered operational mode. The TTS distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para. 4.1 above. Any LRU which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the gamma dose rate test based on the physical geometry and spatial location of the LRUs of the system under test. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size analyzed (usually one). The data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each gamma dose rate exposure. Dosimetry from all LRUs which have a line of sight path to the gamma dose rate source should be removed (please note to leave those which are for measuring the test sequence total dose) and analyzed for dose rate achieved. Utilizing this real time exposure data, the TTS distance should be refined using EQ 5 through 7 above until the desired environment has been realized.

4.3 Gamma Dose Rate Analytical Procedures.

Section 4.2 provides the methods utilized to obtain data during a gamma dose rate environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any gamma dose rate effects are noted, then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The gamma dose rate test environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effect on the system analysis.

4.4 Gamma Dose Rate Follow up.

Follow up to the initial gamma dose rate environment should be performed for each susceptible area. One problem which has been noted in the gamma dose rate environment is the masking of concurrent problems by the destruction of one component. As was discussed earlier, the primary means of electronic circuit failure in a gamma dose rate environment is through the activation of a parasitic SCR device. These parasitic SCRs demonstrate all of the common circuit parameters of the discrete device, in that they have a minimum holding current and voltage. The magnitude of these parameters for a given device is based on the quality of the design flaw. It has been seen that the holding current of latched devices can vary between 60 and 150 mAmps; therefore, an effect called current hogging can play a role in the gamma dose rate test. The current hogging effect is a result of these differences in parasitic parameters, i.e. the device which has the lowest holding current and voltage may allow other latched microcircuits to unlatch, and thereby, protect or mask the other microcircuits. Because of this effect, it is always a requirement to retest a system or LRU which has experienced a gamma dose rate induced failure to insure that another failure mechanism was not originally masked (i.e. replacing the old current hogging device may allow a new device to be destroyed).

5. GAMMA TOTAL DOSE.

5.1 General Gamma Total Dose Procedures.

In this section, the general procedures for performing a gamma total dose (hereafter referred to as gamma dose) test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, assessment can not be made. The second requirement is the realization that the gamma dose environment will be simulated by some form of Cobalt 60 source. These sources are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently these simulators are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the gamma dose gradients are kept to a minimum. The system should also be exposed to increased levels to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one). Ideally the system should be tested one LRU at a time, in order to reduce exposure gradients and to keep the exposure time to less than one minute.

5.2 Detailed Gamma Dose Procedures.

Presented in TOP 1-2-612[4] section 5.6 is a set of data required while performing a gamma dose test. Each of these requ red data will be discussed below:

a. Detailed description of the method of producing the gamma dose test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DNA DASIAC SR-90-252 handbook, and requesting a facilities brochure which should contain a description of the radiation producing method (Co_{60} is the preferred source for low dose rate gamma radiation) and specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas were computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data in radiation absorbed dose in silicon (RAD(Si)) and absorbed dose in tissue (RAD(tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate TTS distances and then refining these TTSs by taking pretest gamma dose environment exposures. For each of these characterization exposures a series of TLDs are placed on the centerline axis of the simulator and exposed. These dosimeter readings are then utilized to calculated each required TTS distance for a given dose rate environment and the exposure time required to achieve a given gamma total dose. This calculation process must be performed for each electronic item to be exposed. The basic dose rate equation is presented as EQ3 and should be verified against the pretest mapping data. EQ4 can be used to select the TTS distance for a given dose rate. The gamma dose rate for the total dose test should be selected between 30 and 300 RAD(Si)/sec and result in an exposure time of approximately one minute. The physical dimensions of the system under test will determine what the highest dose rate used will be. The system test position is selected to minimize the gamma dose gradients, which are calculated using EQ4. Once the TTS distance (which maximizes gamma dose rate and minimizes dose gradient) is determined the time of exposure is calculated using Equation 8.

$$t_{exposure} = \frac{\gamma_{req}}{\dot{\gamma}_{map}}$$

EQ8. Time of Exposure

where

γ_{req} - gamma total dose requirement
$\dot{\gamma}map$ - gamma dose rate at mapping point

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing o. other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the gamma dose rate protection devices (if present) are included and evaluated. In addition, it is necessary to insure that: (1) every electronic assemblage will be properly exposed to the gamma dose environment while in a powered operational state, (2) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the gamma dose environment, and (3) that each assemblage will have mounted to each surface dosimetry for recording the incident gamma dose environment. If gamma dose rate power down has been employed as a circuit protection method, then the gamma dose test should be designed so that the percentage of gamma dose received after the circumvention time, is received with the system in a powered off nonoperational state. The dosimetry at a minimum should be placed on all vertical surfaces (all surfaces if physically possible) of the LRU undertest, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal gamma dose environment of an LRU.

d. Dosimetry from the gamma dose environment.

The TLDs should be placed as indicated in the section above and their location used to determine the gamma exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. The TLD measurement RAD(CaF_2(Mn)) is converted to Tissue and Silicon radiation absorbed dose by EQ. 6 and 7 with the gamma dose rate term replaced by the gamma dose term.

e. System orientation and data.

The system must be oriented such that all of the active electronic LRUs are exposed to the gamma dose environment while in a powered operational mode. The TTS distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial level, the system should be positioned to receive the

200% levels as indicated in para 4.1 above. Any LRU which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the gamma dose test based on the physical geometry and spatial location of LRUs of the system under test. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size analyzed (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each gamma dose exposure. Dosimetry from all LRUs which have a line of sight path to the gamma dose source should be removed (please note to leave those which are for measuring the test sequence total dose) and analyzed for dose achieved. Utilizing this real time exposure data, the TTS distance should be refined using EQ 5 through 8 above until the desired environment has been realized.

5.3 <u>Gamma Dose Analytical Procedures.</u>

Section 5.2 provides the methods utilized to obtain data during a gamma dose environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the orientation in which they were exposed, and the results of the post-test checkouts. If any gamma dose effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The gamma dose test environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effects on the system analysis.

5.4 <u>Gamma Dose Follow up.</u>

Follow up to the initial gamma dose environment should be performed for each susceptible area. This follow up should include both a system or LRU level retest and an electronic microcircuit analysis.

6. <u>NEUTRON FLUENCE</u>.

6.1 <u>General Neutron Fluence Procedures.</u>

In this section, the general procedures for performing a neutron fluence test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, an assessment can not be made. The second requirement is the realization that the neutron fluence environment will be simulated by some form of nuclear reactor. These reactors are all limited in both size and output and are incapable of producing an adiabatic environment over a large area. These reactors all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently the reactors are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the neutron gradients are kept to a minimum. Since the primary damage mechanism for the neutron fluence environment is crystal lattice damage the system under test does not require power during the radiation exposure. Therefore that system should be disassembled to the smallest practical elements in order to reduce neutron exposure gradients and to eliminate the unnecessary neutron activation of non-essential material. By removing and exposing only the active electronic microcircuits the bulk of material making up a system (i.e. shelters, shielding, and enclosures) are not irradiated. Performing the test with the system disassembled reduces the activated volume and thereby reduces the radiation decay (cool down) time and personnel exposures. The system should also be exposed to increased levels in order to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and to allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one).

6.2 Detailed Neutron Fluence Procedures.

Presented in TOP 1-2-612[4] section 5.5 is a set of data required while performing a neutron fluence test. Each of these required data will be discussed below:

a. Detailed description of the method of producing the neutron fluence test environment including photographs of the test facility setup showing test system location relative to the neutron radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DNA DASIAC SR-90-252 handbook, and requesting a facilities brochure which should contain a description of the radiation producing method and specifications. With todays' technology, photographs are considered an antiquated method of archiving a test procedure. The archive and report generation should utilize one of the many computer graphics programs available which can generate clear and concise drawings of the physical test setup. The computer graphics method provides two features of importance over photographs. The first is that the image will not suffer time related degradations. The second is that copies can be generated from the original stored binary data. In those areas were computer graphics produce less than satisfactory results, photographs may be necessary.

b. Complete set of pretest mapping data expressed in 1 MeV equivalent (damage in silicon) neutron/cm^2. Because of the extreme control required in the operation of most reactors the facility will maintain a set of control parameters and dosimetry which can be used to accurately predict experimental exposures. Once a familiarity with the facility has been established there is usually little need for a neutron mapping exposure.

This requirement is obtained by taking several pretest neutron fluence environment exposures. For each of these characterization exposures a series of Sulfur activation dosimetry and TLDs are placed on the centerline axis of the proposed experiment position. These dosimeter readings are then utilized to calculated the required source to target distance for a given neutron environment (for a pulse operation) or the exposure time required to achieve a given neutron dose (for a power operation). The method (pulse or power) of receiving neutron fluence is not of importance as long as the received dose is converted to 1 MeV equivalent damage in silicon. The 1 MeV equivalent conversion is used as a normalization factor between the different types of reactors and operations. Reactors in general are of the water moderated style or the free air mass moderated style, with operations being either pulsed or continuous power. Again the best source found for determining experiment location for a given fluence is the reactor operations crew.

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed. In addition, it is necessary to insure that: (1) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the neutron environment, (2) each exposed assemblage will have mounted to each surface dosimetry for recording the incident neutron environment. This dosimetry at a should be placed on the exposed assemblages at a point on the side which corresponds to the midplane of the active electronic microcircuits (this assumes disassembly to the circuit card assembly level).

d. Dosimetry from the neutron environment.

The sulfur pellets and TLDs should be placed as indicated in the section above and their location used to determine the overall neutron exposure for each specific LRU. The primary method of recording the neutron environment is through the use of sulfur pellets which measure the total neutron energy greater than 3 Mev received. The dosimetry must be changed after every exposure. The sulfur measurement (neutrons/cm^2 greater than 3 MeV) is converted to 1 Mev equivalent damage in silicon by a conversion factor (approximately 6.7 for an experiment at 26 inches for the White Sands Missile Range Fast Burst Reactor). This conversion factor is dependent on the neutron spectrum produced by the reactor and the distance at which the test is performed. Therefore the conversion to 1 MeV equivalent is not generic and must be obtained from the facility dosimetry specialist.

e. System orientation and data.

The system must be oriented such that all of the active electronics are exposed to the neutron fluence environment. This should be accomplished at the Circuit Card Assemblies (CCAs) level if possible, inorder to reduce neutron dose gradients. The TTS distance must be measured before each exposure to insure that the required levels are received. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para. 6.1 above. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to manufacturing processes, and to account for the small sample size analyzed (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each neutron exposure. Dosimetry from all LRUs which have been exposed to the neutron fluence environment should be removed and analyzed for the fluence achieved.

6.3 Neutron Fluence Analytical Procedures.

Section 6.2 provides the methods utilized to obtain data during a neutron fluence environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the CCAs which were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any neutron fluence effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The neutron fluence environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effect on the system analysis.

6.4 Neutron Fluence Follow up.

Follow up to the initial neutron fluence environment should be performed for each susceptible area. This follow up should include both an LRU/CCA level retest and an electronic microcircuit analysis. A total system retest will not be required if the CCA functionality can be verified by an electronic bench test.

Recommended changes of this publication should be forwarded to Commander, U.S. Test and Evaluation Command, ATTN: AMSTE-CT-T, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity, Commander, U.S. Army White Sands Missile Range, ATTN: STEWS-NE-AA, Nuclear Effects Directorate, WSMR NM 88002-5002. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the access number (AD No.) printed on the first page.

APPENDIX A ABBREVIATIONS

ADC	- Analog to Digital Converter
CaF_2(Mn)	- Calcium Fluoride (Manganese)
CCA	- Circuit Card Assembly
cm	- centi-meter
CMOS	- Complementary Metal Oxide Semiconductor
cGy	- centi-Gray (equivalent to one RAD)
Co_{60}	- Cobalt 60
DAC	- Digital to Analog Converter
DC	- Direct Current
DNA	- Defense Nuclear Agency
DOD	- Department of Defense
DODI	- Department of Defense Instruction
EE PAL	- Electrically Erasable Programmable Array Logic
F_T	- Gain Bandwidth Product
GBP	- Gain Bandwidth Product
HOB	- Height of Burst
INR	- Initial Nuclear Radiation
JFET	- Junction Field Effect Transistor
km	- Kilo-meter
kT	- Kilo-Ton
LRU	- Line Replaceable Unit
m	- meter
MeV	- Million Electron Volts
MNS	- Materiel Needs Statement
MOS	- Metal Oxide Semiconductor

MOSFET contractor	- Metal Oxide Semiconductor Field Effect
NIST	- National Institute of Standards and Technology Formally National Bureau of Standards
NMOS	- N-type Metal Oxide Semiconductor
NSA	- Nuclear Survivability Assessment
NHC	- Nuclear Hardening Criteria
ORD	- Operational Requirements Document
PAL	- Programmable Array Logic
PROM	- Programmable Read Only Memory
RAD	- Radiation Absorbed Dose
Si	- Silicon
SCR	- Silicon Controlled Rectifier
SOI	- Silicon on Insulator
SOS	- Silicon on Sapphire
TLD	- Thermoluminescent Dosimeter
TOP	- Test Operation Procedures
TTL	- Transistor Transistor Logic
TTS	- Target to Source
UV	- Ultra Violet

APPENDIX B GLOSSARY

Dose	A general term denoting the quantity of radiation or energy absorbed. In general dose is specified based on absorbing material.
Dosimeter	Instrument to detect and measure accumulated radiation exposure. A common dosimeter is a pencil-size ionization chamber with a self reading electrometer, which is used for personnel monitoring.
Gamma	Gamma radiation emitted at the time of fission of a nucleus.
Gamma Ray	Short-wavelength electromagnetic radiation (photon) of nuclear origin.
Ionization	The process by which a neutral atom or molecule acquires a positive or negative charge.
MeV	One million electron volts. An electron volt is the amount of energy acquired by an electron when it falls through a potential of 1 volt.
Neutron	A neutral molecular particle of approximately one atomic mass unit.
Neutron Fluence	Integral of all neutrons entering a specific volume.
Nuclear Radiation	Particulate and electromagnetic radiation emitted from atomic nuclei during various nuclear processes.
X-rays	Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extranuclear part of the atom as X-rays.

APPENDIX C REFERENCES

1. AR 70-60: Nuclear Survivability of Army Materiel, 1 Nov 84.

2. DODI 5000.2: Defense Acquisition Program Procedures, 11 May 90.

3. Army Nuclear Hardening Criterion for system under test

4. Test Operations Procedure 1-2-612, Nuclear Environment Survivability, 1992.

REFERECES FOR INFORMATION ONLY

a. DASIAC SR-90-252, 1990 Edition: Guide to Nuclear Weapons Effects Simulation Facilities and Techniques.

b. G.C. Messenger and M.S. Ash, The Effects of Radiation on Electronic Systems, published by Van Mostrand Reinhold, 1986.

c. S. Glasstone and P.J. Dolan, The Effects of Nuclear Weapons, published by United States Department of Defense and United States Department of Energy, 1977.

d. Illinois Institute Of Technology Research Institute, Nuclear Weapon Effects Class Notes, 1991.

e. White Sands Nuclear Effects Facility Technical Capabilities, Nuclear Effects Directorate, 1992.